

## ELECTRICAL DEVICE AND OPERATING METHOD

## Field of the Invention

The present invention relates to an electrical device according to the definition of the species in Claim 1 and an operating method according to the definition of the species in Claim 10. Such a device is provided for the combined voltage and torque control of an electrical machine converting mechanical energy to electrical energy, such as a generator in the electrical system of a motor vehicle.

It is known that switching into the vehicle's electrical system an electrical consumer having high electrical power results in a high load on the generator. Since switching on the electrical consumer leads to a voltage dip in the vehicle's electrical system, a voltage controller assigned to the generator tries to increase the power supplied by the generator by increasing the exciting current. However, this results in the braking torque caused by the generator being increased in such a way that, especially in response to a low rotary speed of the internal combustion engine, an interfering sudden drop of the rotary speed may occur. In order to hold such a sudden drop in the rotary speed to as small as possible, measures are provided in systems that have a so-called load-response device which prevents the generator from being loaded too greatly. It is thereby also prevented that a sudden drop in rotary speed occurs in the combustion engine. However, since the required electrical power can no longer be supplied, an undesired voltage dip can now occur.

Such a rotary speed change can be countered, at least in certain operating states, in that a sufficient excess torque is supplied. However, this leads to increased usage, in a

disadvantageous manner. Furthermore, the generator adjustment can be specifically slowed down. However, this may lead disadvantageously to an increase in the fluctuations of the voltage of the vehicle's electrical system. Such fluctuations are undesired, however, since they disadvantageously influence the service life of the battery, and are able to damage component parts that are sensitive to voltage. Furthermore, an additional consumer could be switched on in a specified manner via a ramp function. However, this requires a greater switching technology expenditure, and therefore leads to higher product costs. In all the alternatives mentioned, an optimum adaptation to the actually available excess torque is not readily possible.

A method is known from DE 39 31 897 A1 for voltage control for generators in motor vehicles, in which, in a first time interval, the generator output voltage is set to a maximum value, so that reliable loading of the vehicle's battery takes place, independently of the environmental temperature. In a second time interval, the generator output voltage is regulated usually as a function of the battery temperature, according to a known method. In this context, the establishment of the first time interval takes place as a function of the loading state of the battery.

#### Detailed Description of the Present Invention

The design approach according to the present invention creates a possibility, during operation of the device, to adapt the adjustment speed of the of the voltage situation to the actual speed of the torque provisioning. For this, a coordinated unit is provided which establishes in which way individual variables are set and changed, in order to obtain optimum control. The control concept according to the present invention makes it possible for this coordinating unit to

adjust extreme conditions, such as voltage control at great torque changes, torque control at strong voltage fluctuations, as well as any intermediate conditions. Lastly, this leads to an adaptation of the dynamics of the generator to the actually possible engine dynamics.

The variables voltage and torque are examined in parallel. The generator control may be divided into three areas, in this context.

The first area relates to a voltage control in the immediate surround field of the setpoint voltage, and in response to changes in the braking torque, only up to the set excess torque.

The second area relates to the situation in which the generator cannot adjust the load change and the voltage change using the available excess torque, but the voltage deviation is still just within the admissible boundaries. In this context, the boundary value (excess torque) is able to be changed within the possibilities of the torque buildup in any time-dependent manner. Different strategies may be implemented, in this context, depending on the objective.

The third area relates to the situation in which the vehicle's electrical system voltage lies outside admissible boundaries. In this case the voltage control has the highest priority. The boundaries of the areas mentioned may even, in this context, be displaced at will, within the meaning of optimum adjustment.

#### Brief Description of the Drawings

The present invention is explained below in detail on the basis of the drawing. The figures show:

Figure 1 a first block diagram of a system including a combustion engine and an electrical device having a generator and a vehicle electrical system,

5 Figure 2 a second block diagram having functional modules for the control of the generator,

Figure 3 a third block diagram showing control areas,

Figure 4 diverse curves in one diagram.

#### Variants of the Embodiment

10 Figure 1 shows a first block diagram of a system 1 including a combustion engine and a device having a generator and a vehicle electrical system. Various functional modules are shown schematically, and so are the functional connections between these functional modules. Reference numeral 10  
15 designates a combustion engine, reference numeral 11 designates an electronic engine control assigned to the combustion engine. Reference numeral 12 designates an electric generator which includes an electrical machine 12A and a controller 12B. Electrical machine 12A is driven by combustion  
20 engine 10, and converts the mechanical energy generated by combustion engine 10 to the electrical energy required for a vehicle electrical system. The vehicle electrical system shown only schematically is designated by Reference numeral 13. System 1 also includes a functional module battery management,  
25 which bears reference numeral 14. Vehicle electrical system 13 and generator 12 are linked via load current  $I_{Last}$ . When a strong electrical consumer is switched on in vehicle electrical system 13, such as a rear window heater in the wintertime, a great change with time  $dI_{Last}/dt$  of load  
30 current  $I_{Last}$  takes place, and consequently a high load on generator 12 is triggered. The great change with time of the

load current, in this case a great increase of load current  $I_{Last}$ , leads to a sudden drop in voltage  $U_{Gen}$  that is given off by electrical machine 12A. Electrical machine 12A and controller 12B are linked to each other via the variables  
5 voltage  $U_{Gen}$  and exciting current  $I_{Err}$ . As soon as controller 12B records the drop in voltage  $U_{Gen}$ , it tries to increase the power given off by generator 12 by controlling and corresponding increasing of exciting current  $I_{Err}$ . However, this also increases the braking torque caused by  
10 generator 12. combustion engine 10 and generator 12 are linked to each other via the variables torque  $M$  and rotary speed  $n$ , as well as their changes with time,  $dM/dt$  and  $dn/dt$ . The increase in exciting current  $I_{Err}$  triggered by controller 12B and the increase, effected thereby, of braking torque  $M$  of  
15 generator 12 have an effect on the rotary speed  $n$  of combustion engine 10. Especially in the case of low rotary speeds  $n$  of combustion engine 10, an undesired break of the speed under load may occur. The design approach according to the present invention now creates a possibility, during  
20 operation of the above-described system 1, to adapt the adjustment speed of the voltage to the actual speed of the torque provisioning.

Figure 2 shows a second block diagram in which diverse functional modules are shown for controlling generator 12, and  
25 whose collaboration is shown schematically. Generator 12 includes electrical machine 12A and a controller 12B. Reference numeral 13 designates a functional module representing the vehicle electrical system. Functional module 20 represents the drive train of the vehicle. Reference  
30 numeral 21 designates at least one control unit which coordinates the functional sequence in the control of generator 12. The arrows and double arrows shown in Figure 2

indicate functional linkages that exist between the individual structural components and functional modules.

The crux of the present invention is to create an electrical device, having a generator, in which an extraordinarily  
5 flexible control of the generator is made possible, in order to ensure as great a voltage constancy as possible and as great an operating safety as possible. To do this, according to the present invention, various controlling areas are provided which make possible an optimum controlling strategy.  
10 This is explained in the light of Figure 3, which shows a third block diagram showing controlling areas.

This illustration, in turn, also clarifies the interaction between the vehicle electrical system (functional module 13 in Figure 2) and the drive train (functional module 20 in Figure  
15 2). Altogether, essentially three types of controlling areas may be characterized, which are further subdivided if necessary. In a first area 30, which lies in the immediate surround field of setpoint voltage  $U_{Soll}$ , a voltage control is provided. In this context, if changes in torque  $M$  occur,  
20 these are permitted up to a specifiable boundary value, excess torque  $M_{\text{Überschuss}}$ . To this first controlling area (area 30) there adjoins a controlling area (areas 31, 32) in which generator 12 is not able to adjust occurring load changes and voltage changes using the available, specifiable excess torque  
25  $M_{\text{Überschuss}}$ , the occurring voltage deviation, however, still being within an admissible voltage range. In this context, the admissible voltage range is determined by the specifiable boundary values  $U_H$  and  $U_L$ . Finally, in a third controlling area (areas 33, 34) there is a situation in which the voltage  
30 of vehicle electrical system 13 is outside the admissible voltage range, that is, it exceeds upper boundary value  $U_H$  or undershoots lower boundary value  $U_L$ .

The diagram in Figure 4 shows diverse curves in light of which the functioning of electrical device 1 will be explained below. Curves are plotted over a time axis that represent certain variables as functions of time. Curve 42 shows load current  $I_{Last}$  as a function of time  $T$ . Moreover, torque  $M$  is shown as a function of time  $T$  in curve 41. Finally, generator voltage  $U_{Gen}$  is shown as a function of time  $T$  in curve 40. In addition, in the area of the curve representing the generator voltage, special voltage values are emphasize, namely, a setpoint value  $U_{Soll}$ , a minimum value  $U_L$  and a maximum value  $U_H$ . In this case, setpoint value  $U_{Soll}$  lies between the extreme values  $U_H$  and  $U_L$  named. We shall first examine the time interval between a point in time  $T_0$  and a point in time  $T_1$ . Curve 42 shows that load current  $I_{Last}$  has a certain level and fluctuates only within comparatively narrow boundaries, which indicates an essentially constant load of vehicle electrical system 13. Curve 40, which represents generator voltage  $U_{Gen}$ , shows that generator voltage  $U_{Gen}$  is essentially constant and that it is regulated to its setpoint value  $U_{Soll}$  in the examined time interval  $T_0$ - $T_1$ . Curve 41, representing torque  $M$ , also shows relatively low fluctuations of torque  $M$ , since quite small torque changes are sufficient for compensating for the fluctuations of load current  $I_{Last}$ . Consequently, interval  $T_0$ - $T_1$  corresponds to the first area of control already mentioned above, in which a voltage control takes place in the immediate surround field of setpoint voltage  $U_{Soll}$ , and in which changes of torque  $M$  are admitted up to a specifiable excess torque.

As curve 42 shows, load current  $I_{Last}$  rises steeply at time  $T_1$ , because an electrical consumer has been switched on that has a large power consumption and that loads vehicle electrical system 13. As curve 40 shows, this great load results in a voltage dip. The generator voltage drops below

setpoint voltage  $U_{Soll}$  and approximates lower boundary value  $U_L$ . At this point the second area of control is present, in which generator 12 is no longer able to adjust the load change and voltage change using the specifiable and available excess torque, but the deviation of the generator voltage is still just within the admissible boundary values  $U_H$  and  $U_L$ . In order to compensate for the load change and the voltage deviation connected to it, an increase in torque  $M$  is provided, and the system goes over from voltage control to torque control. Torque  $M$  rises to a higher value until at time  $T_2$  a value of torque  $M$  is reached which is sufficient for compensating the load change. At this time  $T_2$ , generator voltage  $U_{Gen}$  has reached its setpoint value  $U_{Soll}$  again, and a voltage control is carried out again. In this connection, the present invention makes possible an extraordinarily flexible adjustment to difficult operating situations, in order, on the one hand, to compensate for load changes as rapidly as possible, and to guarantee as great as possible a voltage constancy in the process. Thereby great reliability of the vehicle electrical system and as great as possible a protection of voltage-sensitive components are achieved. According to different embodiment variants of the present invention, different strategies may be employed for the control of the torque in the area of torque control. For instance, in a first embodiment variant torque  $M$  may rise linearly, the increase being implementable using different slopes. According to one further embodiment variant, a more complex, nonlinear function may be provided for the rise in torque  $M$ , in addition, dynamic adjustments to the respective situation being also possible in order to attain an optimum result. For example, torque  $M$  may be changed according to a function  $F=F(T, P)$ , where  $T$  is the time and  $P$  is an operating parameter of the device. In a further embodiment variant, a functional dependence of the torque on influencing variables



may be implemented also by a corresponding characteristics map K, in which a certain value of torque M is assigned to corresponding values of one or more influencing variables.

As the course of load current  $I_{Last}$  shows according to curve 42 in Figure 4, load current  $I_{Last}$  drops off greatly at time T3. For example, a strongly powered electrical consumer may have been switched off from the vehicle electrical system. It may be seen from the course of curve 40 that, as a result, generator voltage  $U_{Gen}$  rises sharply and even exceeds maximum value  $U_H$ . At this point the third area, mentioned briefly above, is now present, in which the generator voltage lies outside the admissible boundaries  $U_H$ ,  $U_L$ . In this situation, the voltage control has the highest priority, since voltage-sensitive components or assemblies are greatly at risk. Therefore, as shown in curve 41, it is first taken care that torque M is reduced to a correspondingly low value, in order to attain as fast as possible a voltage drop to a noncritical value. This is the case approximately at time T4, at which the voltage reaches the maximum value  $U_H$  again or falls below it. At this time T4, a torque control sets in again, until the torque that is too high has dropped down to a lower level that is sufficient for the lower power demands, and the voltage has attained its setpoint value  $U_{Soll}$  again. This is the case approximately as of time T5. Beginning at this point in time, the system goes over to voltage control.

With the aid of the curve illustrations in Figure 4, a situation was explained in which a rise in voltage above the maximum value has taken place. An analogous controlling procedure would proceed in response to the undershooting of the minimum value  $U_L$  of the voltage.

In one embodiment variant of the present invention, the values  $U_{Soll}$ ,  $U_H$ ,  $U_L$ , may be specified in an application-specific

manner, as well as the boundaries between the two controlling types torque control and voltage control and the width of the areas in which the respective control type is dominant.

In one particularly advantageous embodiment variant of the present invention, however, it is also possible dynamically to adjust at least some of the variables named, even during driving operation of a vehicle equipped with the electrical device. Thus, for example, the boundaries (see illustration in Figure 3), at which switchover takes place between voltage control and torque control, may be designed as a function of operating characteristics variables of the device or of the vehicle. Such a dependence is able to be expediently implemented by appropriate characteristics maps. In a corresponding manner, the widths of the areas, in which a voltage control or a torque control is to take place, or the transition locations between these two areas, may be designed variably. This embodiment variant is distinguished by particularly great flexibility.

## List of reference numerals

1	system,
10	combustion engine
11	engine control
12	generator
12A	machine
12B	controller
13	vehicle electrical system
14	battery
20	drive train
21	control unit
30	area
31	area
32	area
33	area
34	area
40	curve of voltage
41	curve of torque
42	curve of load current
43	time axis
M	torque
M_Überschuss	excess torque
n	rotary speed
T	time
T0	time
T1	time
T2	time
T3	time
T4	time
T5	time
dM/dt	change in M with time

$dn/dt$	change in n with time
$U_{Gen}$	generator voltage
$U_{Soll}$	setpoint voltage
$U_H$	maximum value of voltage
$U_L$	minimum value of voltage
$I_{Err}$	exciting current
$I_{Last}$	load current
$dI_{Last}/dt$	change in I with time